

The greenhouse effect and global warming

The sun produces radiation mainly in the ultraviolet (UV), visible (vis) and infrared (IR) regions of the electromagnetic spectrum. When these reach the Earth, part is reflected back into space and part of it is absorbed by the Earth's surface. The part which is absorbed heats up the Earth which in turn then radiates some of its energy out into space. The frequency at which any object emits radiation depends on its temperature. The Earth, being that much cooler than the Sun, emits energy at a lower frequency and therefore longer wavelength – in the IR region.

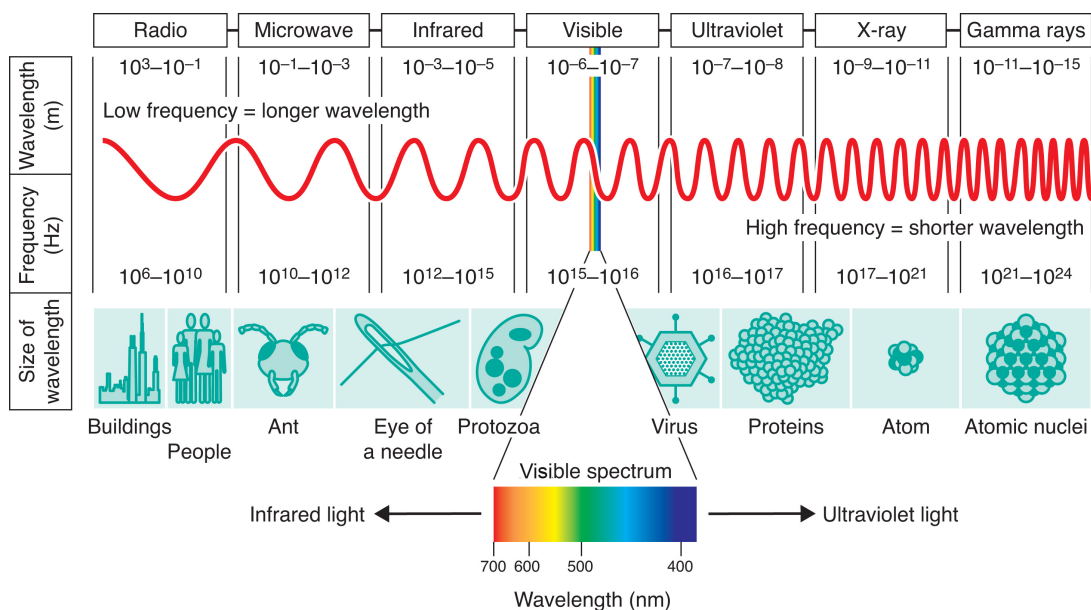


Image above adapted from <http://www.andor.com/printpage.asp?app=331>.

Figure 1. The electromagnetic spectrum.

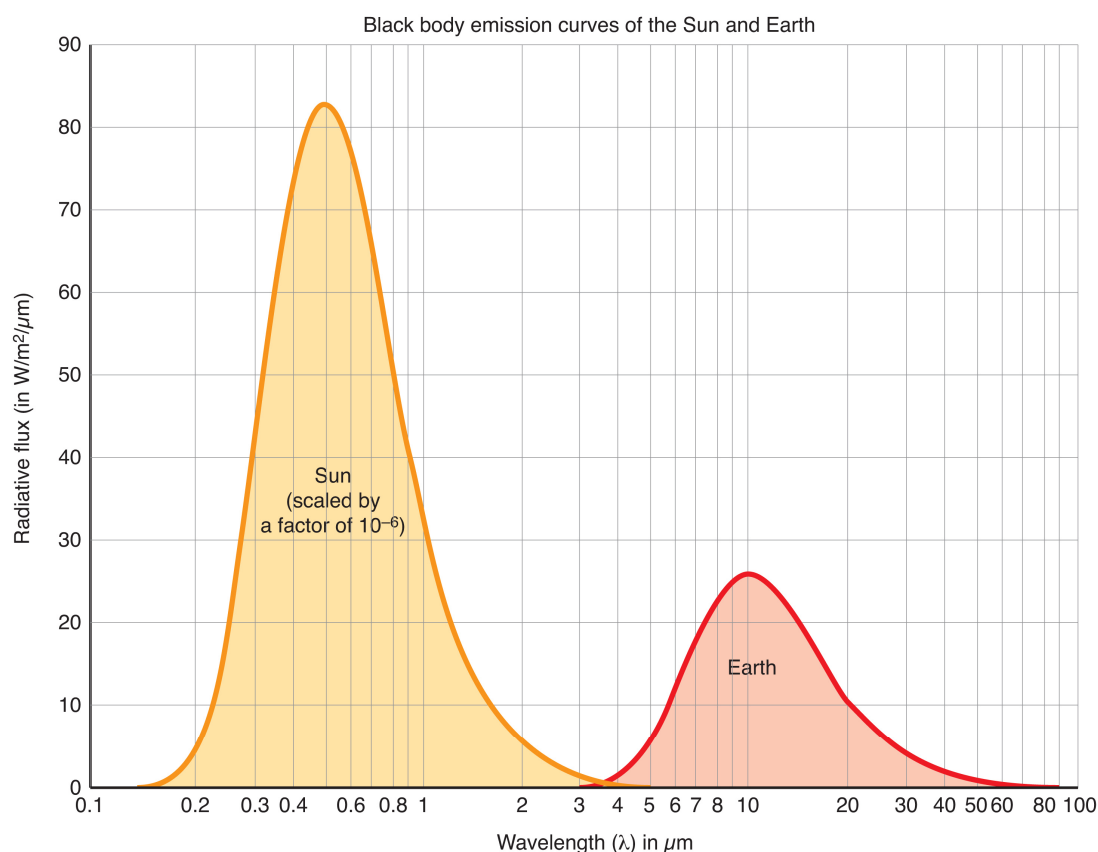
Please note: Some of the graphs in this resource may use units which are unfamiliar, e.g.

$$1 \mu\text{m} = 10^{-6} \text{ m}$$

1 cm^{-1} is the unit used to measure wavenumber and defined as the reciprocal of wavelength ($1 / \text{wavelength}$)

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Adapted from <http://www.ideo.columbia.edu/~kushnir/MPA-ENVP/Climate/lectures/energy/blackbody.gif>.

Figure 2. The energy emissions of the Earth and the Sun.

Note: 'radiance' is a measure of how much light is emitted from an object (in this case, the Earth.)

A steady state is reached where the Earth is absorbing and radiating energy at the same rate, resulting in a fairly constant average temperature. If there were no greenhouse effect at all then the surface temperature would be about 256K or -17°C (about the temperature of a domestic freezer) and life as we know it could not exist because water, the which is fundamental to life, would be a solid. However, the IR radiation emitted by the Earth can be absorbed by gases in the troposphere and become trapped. The radiation is then re-emitted in all directions; some back towards the Earth, which is known as the 'greenhouse effect'. This leads to an increase in temperature and global warming, making the average surface temperature of the Earth about 286K or 13°C. It is an essential part of keeping our planet hospitable and helps to sustain life. The gases which absorb and then re-emit IR are known as 'greenhouse gases.'

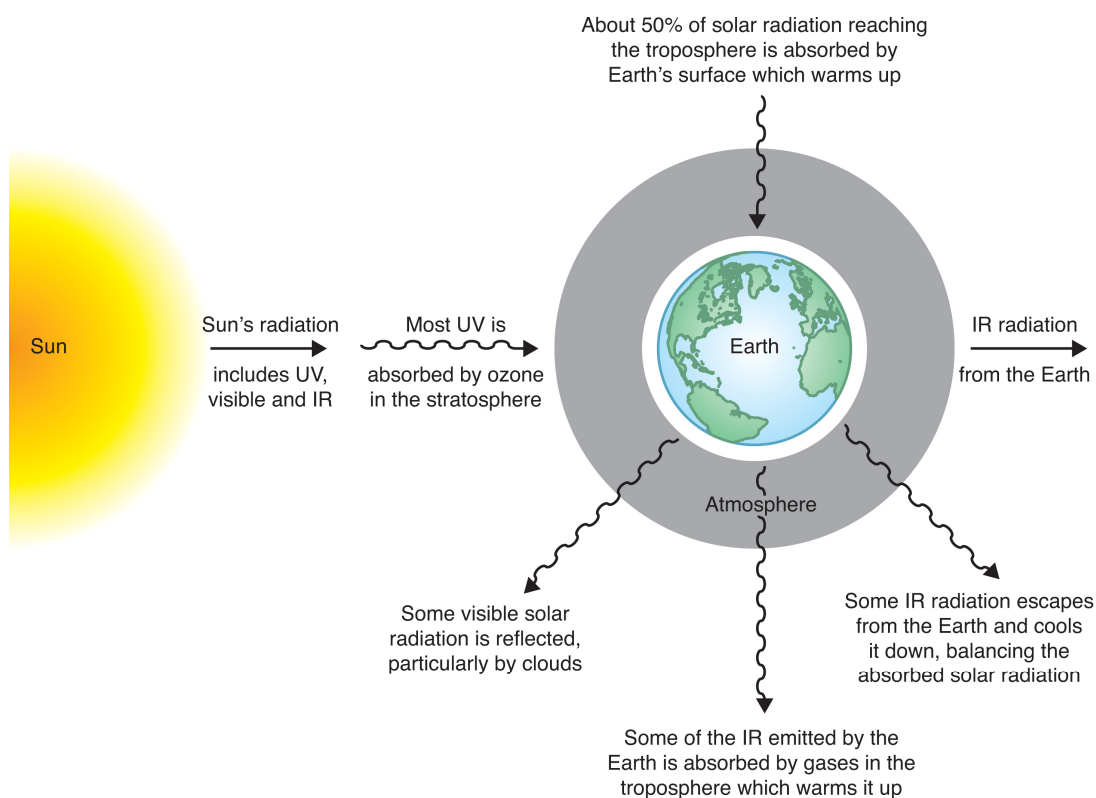


Figure 3. Energy balance of the earth.

Properties of a greenhouse gas

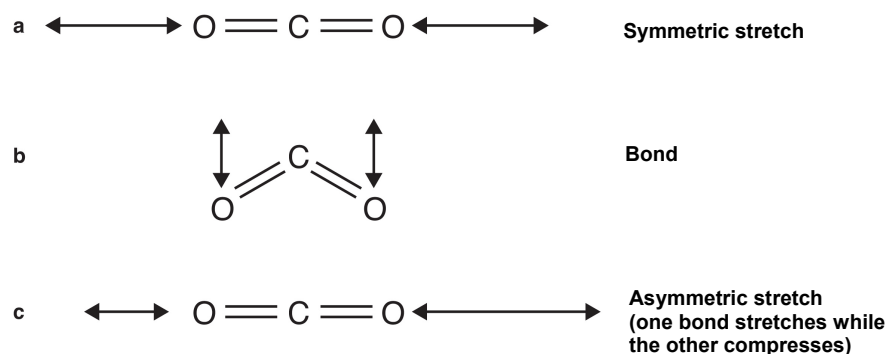
1. A greenhouse gas absorbs infrared radiation

When molecules interact with UV radiation the energy they absorb can break bonds. IR radiation is less powerful as the photons contains less energy. Rather than breaking bonds it causes them to vibrate more energetically. Advanced theory shows that a molecule will absorb IR radiation if the vibration causes a change in its dipole moment.

Oxygen, $\text{O}=\text{O}$, vibrates as a stretching and compression of the bond. Oxygen does not absorb IR radiation as the molecule is symmetrical and does not have a dipole moment – so there can be no change in dipole moment on vibration.

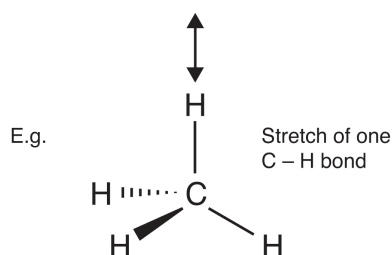


Carbon dioxide, CO_2 , vibrates in three different ways:



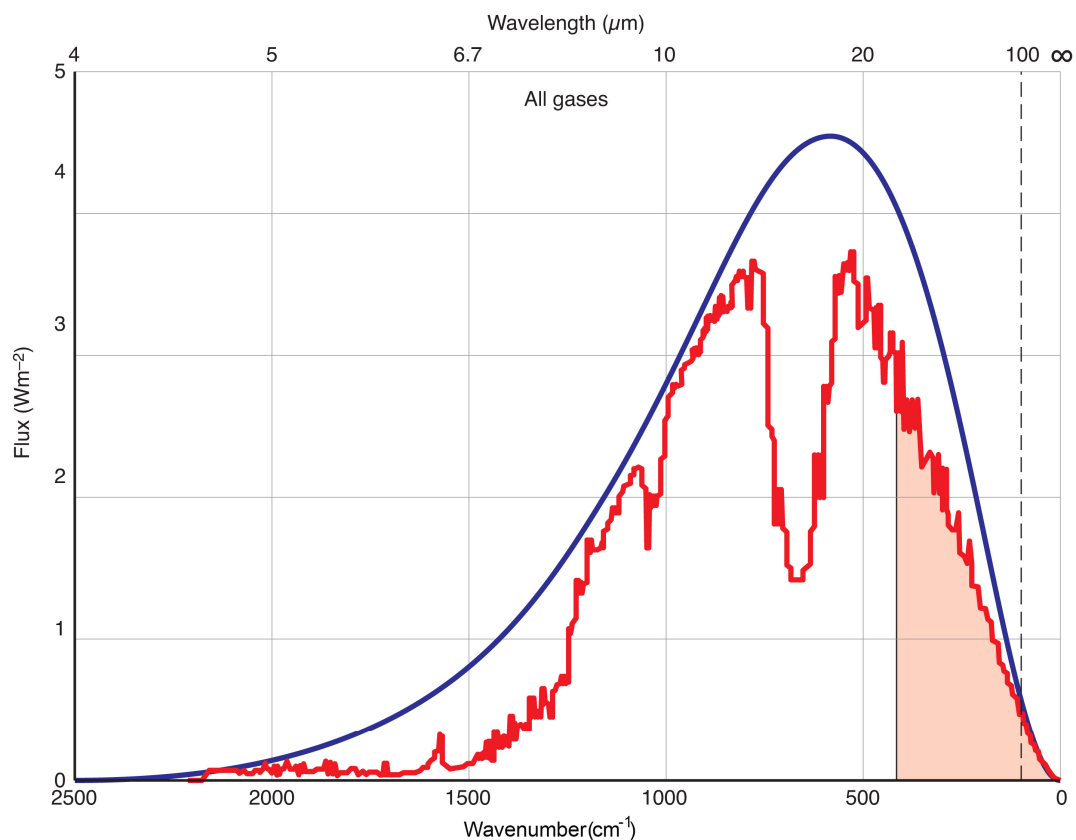
1. Which of the vibrations (a, b, c) will cause a change in dipole moment and so absorb IR radiation?
2. Two other gases which are present in the atmosphere are nitrogen, N_2 , and water vapour, H_2O . Predict whether they will absorb IR radiation.
3. Of these gases which absorb IR radiation in the atmosphere, which is present in the highest concentration?

Methane, CH_4 , is another greenhouse gas. Although it is symmetrical and has no permanent dipole moment, it can vibrate in ways which change its dipole moment and so will absorb IR radiation.



Note: This is a simplified version of the methane stretches. They are shown in full and animated on <http://www.chem.purdue.edu/gchelp/vibs/ch4.html>. (Last accessed November 2008.)

2. A greenhouse gas absorbs energy in the wavelenth range 5-100 μm



Used with permission from Prof Keith Shine at the University of Reading.

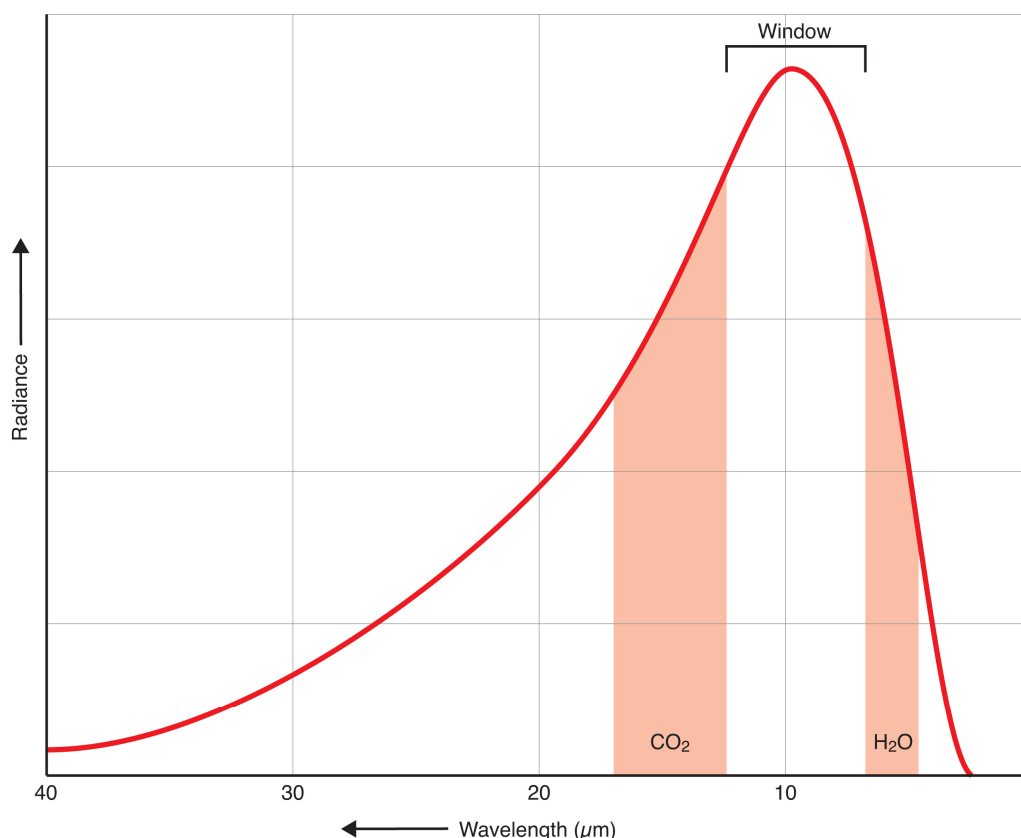
Figure 4. A computer generated typical radiance spectrum of the Earth (red line) and the theoretical (or black body) emission at the Earth's surface (blue line). Radiance is a measure of how much light is being emitted by an object (in this case, the Earth.)

The Earth does not emit much radiation outside the 5-100 μm range and so any gases which absorb other wavelengths will not contribute significantly to the greenhouse effect.

4. Explain why a gas which absorbs IR radiation at 4 μm does not contribute to the greenhouse effect.

Enhanced greenhouse effect

The two most significant greenhouse gases in the atmosphere are carbon dioxide and water vapour. Water makes the bigger contribution (about 60%) to the natural greenhouse effect. Between the absorptions caused by carbon dioxide and water there is a 'window' where the majority of the infrared radiation can escape with relatively little absorption (except for a narrow band where ozone absorbs.) About 70% of Earth's radiation escapes into space through this 'window.'



Adapted from *Salters Advanced Chemistry: Chemical Storylines AS*, published by Heinemann.

Figure 5. A simplified version of Figure 4, showing the Earth's radiation spectrum with the regions where CO_2 and H_2O absorb. Between these two absorptions is the 'window' where the majority of the IR emitted by the Earth escapes.

Gases produced by human activities can increase the natural greenhouse effect of the atmosphere. This is often known as the enhanced greenhouse effect. There are two types of these gases:

- Gases already present in the atmosphere but an increased amount is added by human activities. This includes carbon dioxide and methane. Carbon dioxide contributes the most to the enhanced greenhouse effect.
- Gases which are not naturally present. These can sometimes absorb in the 'window' through which radiation would normally escape into space. This can cause them to have a very large greenhouse effect. CFCs (chlorofluorocarbons) are an example.

The concentration of carbon dioxide is currently about 380 ppm (parts per million) in the atmosphere and is rising by about 0.45% per year. Modellers use a scenario of doubled CO_2 concentration to assess the sensitivity of the Earth's climate system to changes in greenhouse gas concentration. They predict rises of about 1.5–4.5°C. This is not just due to the direct effect of carbon dioxide – there are a large number of feedback processes which amplify the effect of the carbon dioxide.

Carbon dioxide is about 0.03% of the Earth's atmosphere; water is more variable, but at the surface is usually about 1–4% of the atmosphere.

5. Water in the Earth's atmosphere can also cause cooling. Explain how. (Hint: think about cloudy days.)
6. As the Earth warms up, what will happen to the amount of water vapour in the atmosphere? (Hint: think about the water cycle.)
7. As the amount of water vapour increases, what will happen to the temperature?

Climate models run on computers are used by climate scientists to try to predict changes to the Earth's climate. The water in the atmosphere is crucial for these models. The amount of water can be modelled well – it just depends on evaporation and condensation. As the temperature increases, the amount of water which the atmosphere can hold increases. Predicting the behaviour of the water is much harder and is one of the causes of uncertainty in the predictions. Water vapour in the atmosphere can condense to form clouds consisting of water droplets or ice particles. The processes operating in clouds are relatively poorly understood and therefore harder to model and predict, as is the resulting effect on temperature.

Understanding how the climate system works, and the likely effects of adding more greenhouse gases to the atmosphere, are subjects of extensive research by scientists from around the world. Better understanding can help to build better models which give more reliable predictions about the climate of the future.

Summary

8. Explain why some gases in the atmosphere cause the greenhouse effect.
9. Explain the difference between the natural and the enhanced greenhouse effect.
10. List some of the areas of uncertainty or poorly understood parts of the process where further research is required.